Our Docket No: 15685.P024

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	)	
Leifer et al.	)	Examiner: Pablo N. Tran
Application No: 09/336,933	)	Art Unit: 2685
Filed: 6/21/1999	)	
For: NULL DEPENDING FOR AN ADAPTIVE ANTENNA BASED COMMUNICATION STATION	)	

Commissioner of Patents and Trademarks
Washington, D.C. 20231

DECLARATION PURSUANT TO 37 C.F.R. §1.131

Sir:

We, Mark C. Leifer, Tibor Boros, Mitchell D. Trott, and Louis C. Yun, hereby declare that:

1. We are the co-inventors of the above-described patent application and the co-inventors of the subject matter described and claimed therein.

2. We conceived of the invention prior to the June 7, 1999 effective date of U.S. Patent No. 6,141,567 to Youssefmir et al., and were duly diligent from prior to said date to the filing of the present patent application on June 21, 1999, as evidenced by Exhibits A-C.

Exhibit A is a redacted copy of an ArrayComm confidential disclosure of the invention that establishes conception of the invention prior to the June 7, 1999 effective date of U.S. Patent No. 6,141,567 to Youssefmir et al. Determination of signature data is described, at least, in the sections entitled 'Optimal Signature Estimation', 'Recursive Signature Estimation', and 'Signature Estimation'. Realization of improved nulls is described, at least, in the sections entitled 'Null Formation' and 'Null Forming'.

Exhibit B is a redacted copy of a portion of a 1999 day-by-day calendar kept by Dov Rosenfeld the attorney/agent who drafted the present patent application. For each row, the first column lists a date, the third column lists hours recorded, and the fourth column lists a matter for which the hours were recorded. At least the hours recorded for

the matters labeled "null deeper" are hours spent preparing and/or revising the present patent application. Exhibit B, either alone or in combination with Exhibit C, establishes due diligence between prior to June 7, 1999 and the filing of the present patent application on June 21, 1999.

Exhibit C is a copy of an email sent on 6/3/1999 from Dov Rosenfeld the attorney/agent who drafted the present patent application to Tibor Boros and Mitchell Trott providing an attached draft of the present patent application for review. Exhibit C, either alone or in combination with Exhibit B, establishes due diligence between prior to June 7, 1999 and the filing of the present patent application on June 21, 1999.

We hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the above-identified application or an patent issued therefrom.

Respectfully submitted,

Date 3 March ,2006 Mark C. Leifer

Mark C. Leifer

Date________________,2006 ______________________

Tibor Boros

Date________________, 2006 ______________________

Mitchell D. Trott

Date________________, 2006 ______________________

Louis C. Yun

the matters labeled "hull deepen" are hours spent preparing and/or revising the present patent application. Exhibit B, either alone or in combination with Exhibit C, establishes due diligence between prior to June 7, 1999 and the filing of the present patent application on June 21, 1999.

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Respectfully submitted,

Date____________________,2006 ______________________________

Mark C. Leifer

Date MARCH 9 ,2006 Tibor Boros

Tibor Boros

Date____________________, 2006 ______________________________

Mitchell D. Trott

Date____________________, 2006 ______________________________

Louis C. Yun

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Respectfully submitted,

Date__________________,2006 ________________________________
Mark C. Leifer

Date__________________,2006 ________________________________
Tibor Boros

Date March 7, 2006 Mitchell D. Trott
Mitchell D. Trott

Date__________________, 2006 ________________________________
Louis C. Yun

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Respectfully submitted,

Date____________________,2006 ________________________________
Mark C. Leifer

Date____________________,2006 ________________________________
Tibor Boros

Date____________________, 2006 ________________________________
Mitchell D. Trott

Date March 6, 2006 ________________________________
Louis C. Yun

Exhibit A

Improved Signature Estimation and Null Steering For Adaptive Cellular Base Station

--Disclosure of Invention--

[redacted]

This document is ArrayComm CONFIDENTIAL

Inventors:

[redacted]

Other Contributors:

See back page.

Disclosure Status

Invention has not been delivered, offered for sale, or discussed outside of the ArrayComm engineering department. This document is the first written disclosure of this invention. Pages 3, 26-30 from Labbook I (M. Leifer) are attached.

Brief Description of Invention

This invention comprises a method to accurately estimate signatures of simultaneous subscriber units sharing a conventional channel. The accurately estimated signatures are used in a further method to improve a null towards one user in the adaptively formed array steering vector. In providing better rejection of selected interferers, it offers in addition at least a partial solution to the so-called "near/far" problem described below.

In the near/far problem, one subscriber unit SU1 is far from the base station (BS) and another one (SU2) is close. When the weight vector $\boldsymbol{w}_1$ is computed for SU1, signals from SU2 are seen as interference and a null is formed towards SU2. The depth and position of this null are limited by noise and other performance limitations (including the fact that all SU's are adjusted to transmit such that equal power levels are received by the BS). If high power is used to reach SU1 during BS transmit, then excessive signal levels leaking "through" the imperfect null can disturb SU2.

The invention uses additional information known for SU2 when computing weights for SU1. Two methods are proposed: a) the estimated signature $\hat{\boldsymbol{a}}_2$ for SU2 is scaled and added to the received signal vector $\boldsymbol{z}$ prior to weight calculation, so that the weights $\boldsymbol{w}_1$ will contain a null to the known $\hat{\boldsymbol{a}}_2$ or b) the weights are calculated as at present and are then orthogonalized to $\hat{\boldsymbol{a}}_2$. Both methods produce identical improvements in null steering towards SU2 in simulations, although the first method has advantages discussed later. Apart from improving performance, the invention has important implementation features: it is computationally simple and rapid, and it is readily expanded to any number of simultaneous users sharing a channel.

Prior Art

Signature estimation is a generally acknowledged to work poorly in our system, and it is largely avoided (it is used only during the control protocols for channel assignment, to the inventors' knowledge). Nulls are sensitive to noise, and the null depth is observed to vary by 20-30 dB from frame to frame during actual operation! The near/far problem is being addressed at present by degrading hardware performance of close SU's to make them look like far ones. Grouping SU's according to signal strength/distance during channel assignment has also been proposed.

Detailed Description of Invention

The Signature Estimation Problem

The received signal at the base station can be described as

$$z(t) = \sum^{K} a_i s_i(t) + n(t) . \quad \text{(EQ 1)}$$

where $s_i(t)$ denotes the baseband signal transmitted by the ith of K users, a_i is the signature vector of the ith user, and n(t) denotes additive noise (which includes other interfering signals). In matrix form the above signal model can represented as

$$z(t) = As(t) + n(t) \quad \text{(EQ 2)}$$

where

$$A = \begin{bmatrix} a_1 \ a_2 \ \ldots \ a_K \end{bmatrix} \quad \text{and} \quad s(t) = \begin{bmatrix} s_1(t) \ s_2(t) \ \ldots \ s_K(t) \end{bmatrix}^T . \quad \text{(EQ 3)}$$

The base station computes the optimal weight for the ith user by using the well-known formula

$$w_i = s_i Z^H (ZZ^H)^{-1} \quad \text{(EQ 4)}$$

where

$$Z = \begin{bmatrix} z(1) \ z(2) \ \ldots \ z(N) \end{bmatrix} \quad \text{and} \quad s_i = \begin{bmatrix} s_i(1) \ s_i(2) \ \ldots \ s_i(N) \end{bmatrix} . \quad \text{(EQ 5)}$$

Note that the quantity $R_{s_i z} = s_i Z^H$ is computed at the base station for each user in order to form optimal weights. This observation motivates the prior-art method of estimating the signature of the ith user from the simple formula (which gives the optimal MMSE estimate when there is only a single SU)

$$\tilde{a}_i = Z s_i^H (s_i s_i^H)^{-1} . \quad \text{(EQ 6)}$$

This estimate is contaminated by correlations, however, when other users share the same channel, as is seen by substituting Eq. (1) into (6) and noting that

$$Z s_i^H = a_i s_i s_i^H + \sum_{\neq} a_j s_j s_i^H + N s_i^H \quad \text{(EQ 7)}$$

where

$$N = \left[n(1)\ n(2)\ \ldots\ n(N)\right]. \tag{EQ 8}$$

The second term is implicitly assumed to be zero in the prior-art signature estimation of Eq. (6), but this assumption is inaccurate for short data sequences such as the ones used in the ArrayComm WLL basestation. This realization is key to the present invention.

Optimal Signature Estimation

Signature estimation is improved dramatically in the present invention by making use of our knowledge of $s(t)$ (which is found prior to the weight calculation in the present WLL product). The optimal MMSE estimate is given by

$$\hat{A} = ZS^H(SS^H)^{-1} \tag{EQ 9}$$

where S is defined by

$$S = \left[s_1\ s_2\ \ldots\ s_K\right]^T. \tag{EQ 10}$$

For K=2 users, the optimal estimates can be expressed as

$$\hat{a}_1 = Z\frac{s_1^H\|s_2\|^2 - s_2^H(s_2 s_1^H)}{\|s_1\|^2\|s_2\|^2 - (s_2 s_1^H)(s_1 s_2^H)} \tag{EQ 11}$$

and

$$\hat{a}_2 = Z\frac{s_2^H\|s_1\|^2 - s_1^H(s_1 s_2^H)}{\|s_1\|^2\|s_2\|^2 - (s_2 s_1^H)(s_1 s_2^H)}, \tag{EQ 12}$$

respectively. In many cases it might be preferable to compute the optimal signature of a single user in an iterative manner as described in the following section.

Recursive Signature Estimation

Assume that the base station handles two spatial channels (two users communicate with the BS on the same carrier and in the same time slot). The MMSE estimate for the second user can then be computed iteratively in the following manner:

Step 1: Compute the prior-art estimate of a_1 as shown in Eq. (6):

$$\tilde{a}_1 = Zs_1^H(s_1s_1^H)^{-1} \quad \text{(EQ 13)}$$

Step 2: Remove the contribution of the first user from the received signal:

$$\tilde{Z} = Z - \tilde{a}_1 s_1, \quad \text{(EQ 14)}$$

Step 3: Compute the improved estimate of a_2:

$$\hat{a}_2 = \tilde{Z}s_2^H(s_2s_2^H)^{-1} \quad \text{(EQ 15)}$$

Since the correction term subtracted from **Z** in Eq. (14) is itself an approximation, it might seem necessary to iterate Eqs. (14) and (15) to improve the estimate further. The three steps described above, however, produce all of the available improvement, as seen by substituting Eqs. (13) and (14) into Eq. (15)

$$\hat{a}_2 = Z[I - s_1^H(s_1s_1^H)^{-1}s_1]\, s_2^H(s_2s_2^H)^{-1} = Z\,\frac{s_2^H\|s_1\|^2 - s_1^H(s_1s_2^H)}{\|s_1\|^2\|s_2\|^2}\,. \quad \text{(EQ 16)}$$

Equations (16) and (12) differ only by a constant, so the recursive method gives the optimal MMSE solution to within a scale factor.

This recursive method can be extended to incorporate an arbitrary number of users. To estimate the signature for SU3 with three users K=3;

Step 1: Compute $\tilde{a}_1$ from Eq. (13).

Step 2: Form the decorrelated estimate

$$\tilde{a}_2 = \tilde{Z}s_2^H(s_2s_2^H)^{-1}, \quad \text{(EQ 17)}$$

where $\tilde{Z}$ is given in Eq. (14).

Step 3: Iterate the estimate of a_1 with the value of $\tilde{a}_2$ just found,

$$\tilde{a}'_1 = (Z - \tilde{a}_2 s_2)s_1^H(s_1s_1^H)^{-1}. \quad \text{(EQ 18)}$$

Step 4: Compute the optimal estimate of the desired SU,

$$\hat{a}_3 = (Z - \tilde{a}'_1 s_1 - \tilde{a}_2 s_2) s_3^H (s_3 s_3^H)^{-1} . \qquad \text{(EQ 19)}$$

Optimal estimation of signatures for SU1 and SU2 with K=3 results from appropriately changing the indices in this procedure.

To further improve signature estimation in this invention, each desired $\hat{a}_j$ is averaged over successive signal streams (frames) to reduce the contribution of the noise-related error term in Eq. (7). A preferred embodiment employs a weighted moving average which favors recent data. It is further proposed that $\|E[\hat{a}_j] - \hat{a}_j\|^2$ be compared to the variance of $E[\hat{a}_j]$ for each new frame as a means of evaluating stationarity, and that the averaging be restarted if the new signature estimate significantly deviates from the mean.

Null Formation

The improved signature estimate is used in the two following procedures to produce better nulls in w_i towards a_j.

Method 1.

In this preferred embodiment, estimated signatures from undesired SU's are scaled and added to z before finding weight values, that is,

$$Z_i(t) = z(t) + \sum_{\neq} \alpha_j \hat{a}_j s_j(t) \qquad \text{(EQ 20)}$$

is used in place of z in Eq. (4) to find w_i. The scale factor α can be set to a large fixed value to force a deep accurate null towards each undesired SU signature. A preferred embodiment makes α a function of the relative power levels transmitted to the ith and jth SU's (or to some similar measure derived from received signal strengths, etc.), forming deep nulls only where needed. Using weak nulls where allowable would reserve degrees of freedom for use elsewhere (to null additional noise sources, for instance).

Method 2.

The weight vector w_i may be orthogonalized to the estimated signatures after it is calculated from the Wiener solution, using the Gram-Schmidt orthogonalization

$$\hat{w}_i = w_i - \sum_{j \neq i} \frac{w_i^H \hat{a}_j}{\|\hat{a}_j\|^2} \hat{a}_j . \tag{EQ 21}$$

In simulations with two SU's and random noise, methods 1 and 2 produced identical null improvements. A disadvantage of Method 2, however, is that it may disturb nulls which were formed towards "coherent" noise sources (eg., from neighboring cells) or towards other incoherent interferers, and may have an effect on the "main lobe" towards the desired SU. Method 1 is therefore preferable because it forms the main lobe, and nulls towards all interferers, simultaneously.

Results of Simulations

Simulations were run with signals from two SU's consisting each of N randomly generated symbols coded by $\pi/4$ DPSK. Random noise was added to give a selected SNR at each of 12 antennae.

Signature Estimation

The signature $\hat{a}_2$ is formed according to the prescription above and averaged over a number *Navgs* of random trials. The estimation accuracy is measured by the dot product

$$c = \frac{|\hat{a}_2^H a_2|}{\|\hat{a}_2\| \|a_2\|}, \tag{EQ 22}$$

which equals one for perfect correlation. Each value c in the table below represents the mean of the values from 1000 random trials. An additional measure is the quantity

$$I = 20\log\left(\frac{1 - c(\text{prior art})}{1 - c(\text{decorr})}\right) \tag{EQ 23}$$

giving the *improvement* I in dB of the signature estimated by the new decorrelated vector method of this invention over that estimated by the prior art Eq. (6). This is also listed in Table 1.

Table 1: Accuracy of New Signature Estimator

K	N	$Nruns$	$Navgs$	SNR	c (prior art)	c (new)	I (dB)
2	50	1000	1	200 dB	0.9906	1.0000	∞
2	50	1000	1	4.2	0.9878	0.9963	10.6
2	50	100	10	4.2	0.9987	0.9996	10.2
3	50	1000	1	200	0.9821	1.0000	65.1

Even when the signals are essentially noiseless, the prior art estimator suffers from errors (see first line of Table 1) arising from the signal correlation effects discussed earlier. By contrast, c for this case with the new estimator is exactly 1 to within Matlab's 15 digits of displayed precision! The SNR of 4.2 dB per antenna in the remaining rows corresponds to our design target of 15 dB overall SNR for a 12 element array. Note that the signature estimate is about 10 dB better with the method of this invention, independent of the number of frames averaged over. The last row shows the result for the recursive estimator with three SU's. The dot product c differs from unity by one part in 10^5. Using the exact estimator of Eq. (9) gives unity to Matlab's 15 digits of precision.

Null Forming

Simulations were also run to evaluate the use of the improved signature estimator in producing effective nulls. The signature was averaged over *Navgs* frames, then the means and standard deviations of the null depth *ND,* defined by the dot product

$$ND = \frac{\left|\hat{w}_2^H a_2\right|}{\|\hat{w}_2\|\|a_2\|}, \qquad \text{(EQ 24)}$$

were calculated for each of the *Navgs* cases. The experiment is averaged over *Nruns*=100 trials as before for the Wiener solution and for methods 1 and 2. These data are tabulated on pgs. 28-29 of the Labbook and show identical results for the two methods. Shown in the summary table below is the quantity 20log(*ND*/*ND*1,2) giving the improvement in null depth in dB as *SNR*, *Navgs* and

N are varied.

Table 2: Improvement in Null Depth

N	$Navgs$	SNR	$dB1$	$dB2$
50	10	-5 dB	10.3 dB	10.3 dB
50	10	0	11.1	11.1
50	10	4.2	10.2	10.3
50	10	10	10.3	10.3
50	10	20	9.9	9.8
50	2	4.2	2.8	2.8
50	4	4.2	5.9	5.9
50	10	4.2	10.2	10.3
50	20	4.2	13.8	13.8
100	10	4.2	10.6	10.6
100	20	20	13.4	13.4
100	100	200	20.3	20.3

The dB improvement with signal averaging closely follows the familiar $\sqrt{Navgs}$ dependence, as is clear from the plot in Fig. 1.

A final observation noted during the simulations: signature estimation improves with the correlation correction, and improves further with averaging. Null accuracy improves only when both decorrelation and averaging are used together.

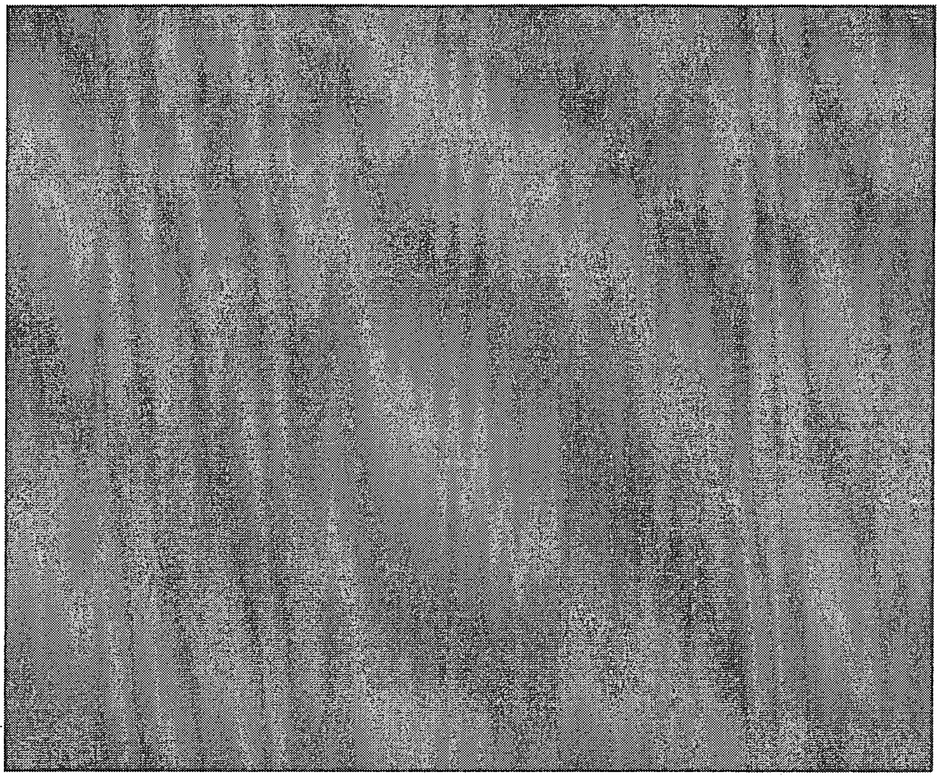

Figure 1. Improvement in null depth scales as the square-root of number of averages.

Contributors

[redacted]

Conceived of Method 1 of improving nulls and method of improving signature estimates. Realized roles of signal correlation and random noise in limiting performance, developed iterative method of removing correlated portions of signal vector. Performed simulations, etc. with [redacted]

[redacted]

Provided firm mathematical framework, and extended method to more than two SU's. Wrote Matlab simulation code, worked with [redacted] on simulations, etc.

[redacted]

Suggested Method 2 of after-fact orthogonalization.

[redacted]

Suggested after hearing initial idea that signal averaging would improve performance.

[redacted]

Explained simulation results by demonstrating that 2-SU recursive solution is mathematically same as optimal MMSE to within scale factor.

Signatures

Inventor	Date
Inventor	Date

I have read and understood this disclosure and acknowledge 6 attached photocopied labbook pages.

Witness	Date

Exhibit B

Date	Client	Time	Subject	
[redacted]				
6/1/1999	ArrayComm	0:30	General: Mitchell:	
6/1/1999	ArrayComm	1:15	Null deepen:	
6/1/1999	ArrayComm	2:00	Null deepen:	
6/1/1999	ArrayComm	1:00	General: Hank, Lisa, etc.:	
6/1/1999	ArrayComm	2:00	Null deepen:	
6/2/1999	ArrayComm	2:00	prepare prenulling:	
6/2/1999	ArrayComm	4:30	ArrayComm visit:	
6/2/1999	ArrayComm	2:00	New Appt.:	
6/3/1999	ArrayComm	4:15	prenulling:	
6/3/1999	ArrayComm	1:00	nulldeepen:	
6/3/1999	ArrayComm	0:15	dave/mitch:	
6/3/1999	ArrayComm	1:15	pre-nulling:	
6/7/1999	ArrayComm	0:30	New Appt.:	
6/7/1999	ArrayComm	0:30	General: go over files:	
6/7/1999	ArrayComm	1:15	031- CDMA review CDMA:	
6/7/1999	ArrayComm	1:15	foreign budget for 1999:	
6/7/1999	ArrayComm	0:30	General: Agt related:	
6/7/1999	ArrayComm	1:45	030- File 030:	
6/7/1999	ArrayComm	2:15	null deepen:	

6/8/1999	ArrayComm	3:00	null deepen:	
6/8/1999	ArrayComm	2:45	null deepen:	
6/9/1999	ArrayComm	4:45	null deepen:	
6/10/1999	ArrayComm	0:45	null deepen:	
6/10/1999	ArrayComm	7:00	null deepen:	
6/11/1999	ArrayComm	1:00	null deepen:	
6/11/1999	ArrayComm	0:30	sevearl continuations, etc.:	
6/11/1999	ArrayComm	5:45	null deepen:	
6/14/1999	ArrayComm	2:00	null deepen:	
6/14/1999	ArrayComm	0:30	ed berkpwitz:	
6/14/1999	ArrayComm	2:00	null deepen:	
6/14/1999	ArrayComm	3:15	null deepen:	
6/15/1999	ArrayComm	2:00	null deepen:	
6/15/1999	ArrayComm	5:15	null deepen:	
6/16/1999	ArrayComm	0:30	formal drawings -17:	
6/16/1999	ArrayComm	1:00	Hank re ArrayComm work:	
6/16/1999	ArrayComm	0:30	emails:	
6/16/1999	ArrayComm	4:00	null deepen:	
6/17/1999	ArrayComm	1:45	Null deppen:	
6/17/1999	ArrayComm	4:00	Cal Ward:	
6/17/1999	ArrayComm	3:30	Cal Ward:	
6/18/1999	ArrayComm	3:30	Cal Ward:	
6/21/1999	ArrayComm	1:45	null deepen:	
6/21/1999	ArrayComm	0:15	Berkowitz:	
6/22/1999	ArrayComm	0:30	Mail/email/phone:	
6/23/1999	ArrayComm	5:00	Go to ArrayComm. Ed Berkowitz.: Ed Berkowitz.	1-650-494-2099
6/28/1999	ArrayComm	1:00	Several Townsend matters/Mitch:	
6/29/1999	ArrayComm	0:15	General: emails:	
6/30/1999	ArrayComm	0:15	Crendal:	
[redacted]				
			June/99	
[redacted]				
ArrayComm	501	98.25		
[redacted]				

Exhibit C

To: Tibor Boros <tibor@arraycomm.com>,mitch@arraycomm.com
From: Dov Rosenfeld <dov@inventek.com>
Subject: nulldeepen
Cc:
Bcc:
Attached: C:\aaa-----INVENTEK CLIENTS\Arraycomm\Patents\CURRENT\Null deepening MarkL 026\nulldeepen-6-3-99.ps;

Here is the postscript. Per our conversation, there is still lots of work to do.

Be well,

DOV

Dov Rosenfeld, INVENTEK dov@inventek.com
5507 College Ave, Suite 2 +1-510-547-3378 voice
Oakland, CA 94618, USA +1-510-291-2985 fax
+1-510-654-5522 home